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# Increased plant density and reduced N rate lead to more grain yield and higher resource utilization in summer maize

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**Abstract**

Planting at an optimum density and supplying adequate nitrogen (N) to achieve higher yields is a common practice in crop production, especially for maize (*Zea mays* L.); however, excessive N fertilizer supply in maize production results in reduced N use efficiency (NUE) and severe negative impacts on the environment. This research was conducted to determine the effects of increased plant density and reduced N rate on grain yield, total N uptake, NUE, leaf area index (LAI), intercepted photosynthetically active radiation (IPAR), and resource use efficiency in maize. Field experiments were conducted using a popular maize hybrid Zhengdan 958 (ZD958) under different combinations of plant densities and N rates to determine an effective approach for maize production with high yield and high resource use efficiency. Increasing plant density was clearly able to promote N absorption and LAI during the entire growth stage, which allowed high total N uptake and interception of radiation to achieve high dry matter accumulation (DMA), grain yield, NUE, and radiation use efficiency (RUE). However, with an increase in plant density, the demand of N increased along with grain yield. Increasing N rate can significantly increase the DMA, grain yield, LAI, IPAR, and RUE. However, this increase was non-linear and due to the input of too much N fertilizers, the efficiency of N use at $N_{CK}$ (320 kg ha$^{-1}$) was low. An appropriate reduction in N rate can therefore lead to higher NUE despite a slight loss in grain production. Taking into account both the need for high grain yield and resource use efficiency, a 30% reduction in N supply, and an increase in plant density of 3 plants m$^{-2}$, compared to LD (5.25 plants m$^{-2}$), would lead to an optimal balance between yield and resource use efficiency.

**Keywords:** summer maize, increased plant density, reduced N rate, N use efficiency, resource use efficiency

## 1. Introduction

Increasing plant density is a common technique for achieving higher grain yield, as it increases the potential capacity of the crop canopy to capture resources including solar radiation, water and nutrients (Duan 2005). Although high plant density also increases interplant competition for resources and reduces grain yield per plant (Tetio-Kagho and Gardner 1988; Tollenaar and Wu 1999; Rossini *et al*. 2011; Al-Naggar *et al*. 2015), the use of hybrids tolerant of high densities and responsive to improvements in fertilization management

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practices could overcome the negative impacts of competition and lead to maximized maize (*Zea mays* L.) productivity per unit area (Bangizer *et al*. 1999; Rossini *et al*. 2011).

In recent years, nitrogen (N) rate in maize production has far exceeded the agronomic and economic optimums, leading to a sharp reduction in the recovery of N in soil-plant systems (Raun and Johnson 1999) and severe negative impacts on the environment and human health (Snyder *et al*. 2009; Huang and Tang 2010; Chen *et al*. 2011). Thus, it is imperative to develop agronomic practices that allow for reduced N rates in agricultural production.

Grain yield in maize is determined mainly by the final number of kernels per unit area that reach maturity, a measurement that is determined by kernel numbers per ear (KN) and ear density. Management practices, such as N fertilization (Uhart and Andrade 1995; Rossini *et al*. 2011) and plant density (Maddonni *et al*. 2006), could affect both KN and ear density, and, consequently, final KN. Under limited N conditions, the N fertilizer supply usually leads to increases in kernels per unit of ground area and mean kernel weight (KW) (Lemcoff and Loomis 1986; Thiraporn *et al*. 1987, 1992; Oikeh *et al*. 1998). However, studies have found that, when the N rate reaches a sufficiently high level, these increases diminish, and both KN and mean KW might even decline (Kniep and Mason 1989).

High plant density is also needed to obtain high yield in maize (Tokatlidis *et al*. 2011). However, as plant density increases, the KN per plant is reduced (Edmeades and Daynard 1979; Maddonni and Otegui 2004), while KW is either not affected (Tetio-Kagho and Gardner 1988) or is reduced slightly (5–30%; Borrás *et al*. 2003; Sangoi *et al*. 2002), resulting in a decline in grain yield per plant (Edmeades and Daynard 1979; Tetio-Kagho and Gardner 1988).

Maize grain yield is determined by the product of total dry matter and its partitioning to kernels. When other factors are not limited, crop biomass production can be represented as the product of two major components: the amount of accumulated intercepted radiation ($RI_{acc}$) (Sinclair and Muchow 1999; Boomsma *et al*. 2009) and the efficiency of conversion into dry matter, also referred to as radiation use efficiency (Monteith 1977; Sinclair and Muchow 1999; Boomsma *et al*. 2009). The $RI_{acc}$ depends on the fraction of radiation intercepted ($RI_{frac}$) by the canopy each day, the days over which radiation is intercepted and total incident solar radiation. The $RI_{frac}$ by a crop canopy depends on the canopy leaf area index (LAI) and the canopy light extinction coefficient ($k$) according to Beer's law. Consequently, many studies have focused on these two parameters (Nilson 1971; Suits 1971; Campbell 1990; Wang *et al*. 2007). For maize, authors have reported values of $k$ ranging from 0.40 (Kiniry *et al*. 1989) up to 0.72 for inbred strains with more horizontal leaves (Pepper *et al*. 1977).

Numerous studies have reported that increases in N rate and plant density lead to significant increases in maize dry matter accumulation (DMA, Ciampitti and Vyn 2011; Cheng *et al*. 2015 ). This rise in DMA is due to an increase in the LAI and a corresponding increase in the $RI_{frac}$ (Maddonni *et al*. 2006). The radiation use efficiency (RUE) also appears to increase with N rate and plant density increased (Muchow and Davis 1988). Massignam *et al*. (2009) reported that the RUE of maize in the whole crop cycle rose from 1.07 to 2.08 g $MJ^{-1}$ after the addition of 30 g $m^{-2}$ of N and from 1.08 to 1.24 g $MJ^{-1}$ when plant density was increased from 3.33 to 6.67 plants $m^{-2}$.

In the North China Plain (NCP), smallholder farmers typically double-crop summer maize with winter wheat (*Triticum aestivum* L.), producing average maize yield of 7.81 t $ha^{-1}$ (Jin *et al*. 2012). Average N rate in the region reach 360 kg $ha^{-1}$ (Zhang 2008); however, the density of summer maize in smallholder fields in the NCP is generally less than 60 000 plants $ha^{-1}$. Therefore, agricultural strategies that are able to achieve higher yield and resource use efficiency, while focusing on an increase in plant density and reduction in N rate, would be welcome. The specific objectives of this study were to assess the effects of higher plant density and less N rate on (i) total N uptake, N use efficiency (NUE), (ii) DMA, LAI, $RI_{frac}$, and RUE and (iii) grain yield and its components in maize grown under field condition, in order to determine an effective approach for maize production with high yield and high resource efficiency in the NCP.

## 2. Materials and methods

### 2.1. Field site and growing conditions

Field experiments were conducted in 2013 and 2014 at the Corn Research Center (36°10´N, 117°09´E) of Shandong Agricultural University, Tai'an, Shandong Province, China. The soil type was a neutral sandy loam, composed of 9.84 g $kg^{-1}$ organic matter, 0.79 g $kg^{-1}$ total N, 47.19 mg $kg^{-1}$ available phosphate, and 84.23 mg $kg^{-1}$ available potassium in the top 0–20 cm arable soil layer. Meteorological data during the maize growing seasons were recorded by an automatic weather station installed in the field (Fig. 1). There were no significant differences between the weather data from the two years, except for precipitation.

### 2.2. Experimental design

Zhengdan 958, a compact maize cultivar tolerant of high plant density, was used as the experimental material. Three planting used were 52 500, 67 500 and 82 500 plant $ha^{-1}$ (henceforth referred to as LD, MD and HD, respectively, and